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PRODUCTION RESPONSE TO GROUNDWATER POLLUTION CONTROL

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Contamination of groundwater by agricultural practices presents a dilemma between protecting a vital resource and preserving a valuable part of the economy. A model is developed to reflect the current state of agriculture in Eastern Suffolk County. This model consists of a recursive programming component, which has input for it generated by a model of Colorado potato beetle pest dynamics and management strategies to control those pests.

The model is run under different policy settings, which include no regulation, taxation of pesticides, ban of selected pesticides, forced crop rotations, taxation of potatoes, purchase of crop rights, ban of potatoes, and the development of pest control districts. The last eight of these policy settings take as given the ban on pesticides. While income is reduced by banning pesticides, the reduction is small when compared with the improvement in environmental quality. Further efforts to reduce pesticide use resulted in a reduction in potato acreage and incomes, as well as yields.

While short-run economic considerations would favor the status quo, a broader long-run perspective encourages further efforts to reduce pesticide use and coordinate economic and environmental considerations.

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Introduction

Pesticide contamination of groundwater has been reported in many states. Efforts have been made to prevent further contamination, but environmental agencies are often reluctant to put too much regulatory pressure on agriculture. Part of this stems from the ambivalence of the public surrounding agriculture, the economy and the environment. On the one hand, neighbors view agriculture positively as a protector of open space and mainstay for the economy. On the other hand, agricultural pollution can be aesthetically displeasing for many of these same people, and even health threatening in some cases.

One region where the dilemma has been particularly acute is Eastern Suffolk County, on Long Island in New York State. Suffolk County leads New York State in agricultural commodity sales. While there are a wide variety of crops produced on Long Island, the most important has been potatoes. Potato monocropping has lead to escalating pest control requirements. To combat pests such as the Colorado Potato Beetle, farmers have felt compelled to apply pesticides. Some of these pesticides used to control the CPB have been found in the groundwater. Three of these, aldicarb, carbofuran, and oxamyl, have been banned for use on Long Island.

This paper examines the economic and environmental effects of different policies which are designed to protect groundwater from pesticide contamination. To do this, a model is developed. Alternative policies regulating pesticide use and encouraging cultural practices which are presumably less likely to have an adverse affect on groundwater are incorporated in this model. The model is then used to compare the different policies effect on income, hazard of contamination, and acute health risk.

A Model of Long Island's Agriculture

The model used to analyze Long Island agriculture's impact on groundwater under different policies has three components: a recursive regional programming model, a biological model of Colorado potato beetle population dynamics, and indices of groundwater quality. These three components are then integrated by using their common variables. Output from the biological model serves as input for the economic model. Output from the economic model is used to evaluate the potential for groundwater leaching, and acute health hazards.

To reflect farm decision making, the objective function of the model seeks to maximize farmer gross margin, that is, gross receipts over variable costs. The objective function can be expressed as

$$(1) \quad \text{MAX} \sum_{i=1}^{17} p_{it}\, y_{it} - \sum_{i=1}^{17} \sum_{l=1}^{8} c_{it}\, x_{ilt} - \sum_{\psi=1}^{21} c_{\psi t}\, \Psi_{\psi lt} - \sum_{\tau=1}^{3} w_t\, HLAB_{\tau t} + \sum_{l=1}^{8} A_{lt}\, SELLAND_{lt}$$

where p_{it} is the price of crop i in year t; y_{it} is the amount of crop i produced in year t; c_{it} is the variable cost per acre of producing crop i in year t, not counting labor and pesticide variable costs; x_{ilt} is the number of acres of crop i grown on land l in year t; $c_{\psi t}$ is the cost of pesticide ψ in year t; $\Psi_{\psi lt}$ is the amount of pesticide Ψ used in year t; w_t wage of hired labor in year t; $HLAB_{\tau t}$ is the amount of labor hired in season τ of year t; A_{lt} is the price per acre of land l in year t; $SELLAND_{lt}$ is the number of acres of land l sold in year t. Data for prices and costs used in the model are explained in Baker (1985). This objective function is subject to several constraints. The first constraint is the land constraint.

$$(2) \qquad \sum_{i=1}^{17} x_{ilt} + SELLAND_{lt} \leq \overline{LAND}_{lt}$$
$$l=1, \ldots, 8.$$

Where $\overline{LAND}$ = the total amount of land of type l in production in year t. The next constraints are on the amount of labor which is available to the farm sector.

$$(3) \qquad \sum_{i=1}^{17} \sum_{l=1}^{8} a_{is\tau} x_{ilt} + \sum_{i=1}^{17} \sum_{l=8}^{8} \sum_{\psi=1}^{21} a_{\psi st} \Psi_{\psi lt} \leq FLAB_{\tau t}$$
$$\tau = \{1, \ldots, 3\}$$

$$(4) \qquad \sum_{i=1}^{17} \sum_{l=1}^{8} a_{iu\tau} x_{ilt} + \sum_{i=1}^{17} \sum_{l=1}^{8} \sum_{\psi=1}^{21} a_{\psi ut} \Psi_{\psi lt} \leq HLAB_{\tau t}$$
$$\tau = \{1, \ldots, 3\}$$

$$(5) \qquad FLAB_{\tau t} \leq \overline{FLAB}_{\tau t}$$

$$(6) \qquad HLAB_{\tau t} \leq \overline{HLAB}_{\tau t}$$

Where $FLAB_{\tau t}$ is the amount of skilled (family) labor used in season τ of year t, $\overline{FLAB}_{\tau t}$ and $\overline{HLAB}_{\tau t}$ are the upper limits on family and hired labor in season τ of year t. The technical coefficients are represented by a_{ist}, a_{iut}, $a_{\psi st}$, and $a_{\psi ut}$, labor required by crop i, unskilled labor required by crop i, skilled labor required to apply pesticide ψ and unskilled labor required to apply pesticide ψ, respectively.

Transfer rows used to link production to sale of the different crops are represented by equation 7.

$$(7) \qquad \sum_{v=1}^{V} \sum_{l=1}^{8} a_{ilvt} x_{ilvt} = y_{it}$$

$$i = \{1, \ldots 17\}.$$

Where a_{ilvt} is the yield for crop i, land type l, pest control program v in year t. Flexibility constraints for each crop are calcuated by multiplying the flexibility coefficients, $\bar{\beta}_i$ and $\underline{\beta}_i$, the upper and lower bounds for crop i, respectively, by the amount of crop i grown in period t-1.

These constraints are stated as follows:

$$(8) \qquad \sum_{l=1}^{8} x_{ilt} \leq (1 + \bar{\beta}_i) x_{i(t-1)}$$

$$i = \{1, \ldots ,17\}$$

$$(9) \qquad \sum_{l=1}^{8} x_{ilt} \geq (1 - \underline{\beta}_i) x_{i(t-1)}$$

$$i = \{1, \ldots ,17\}$$

The flexibility constraints were estimated from time series data. A conservative approach was taken, one which would tend to err by overestimating upper limits and underestimating lower limits. The formulae for estimation are given by equations 10 and 11.

$$(10) \qquad \bar{\beta}_i = \mathrm{MAX} \left\{ \frac{x_{it} - x_{i(t-1)}}{x_{i(t-1)}} \right\} \quad \text{for } x_{it} > x_{i(t-1)}$$

$$(11) \qquad \underline{\beta}_i = \mathrm{MIN} \left\{ \frac{x_{it} - x_{i(t-1)}}{x_{i(t-1)}} \right\} \quad \text{for } x_{it} < x_{i(t-1)}$$

The flexibility constraints are determined by the cropping pattern from the previous year and the flexibility coefficients, $\bar{\beta}_i$, $\underline{\beta}_i$.

Irrigation is an important consideration when modeling groundwater contamination. Removal of groundwater for irrigation exacerbates groundwater quality problems. When irrigation water is applied, the chemicals in the vadose zone are more easily transported to the saturated zone. Equation 12 gives the maximum amount of land which can be converted from non-irrigated use to irrigation.

$$(12) \qquad \sum_{l \varepsilon I} x_{lt} \leq \sum_{l \varepsilon I} x_{l(t-1)} \quad \sum_{l \varepsilon U} \beta_{\lambda} \; x_{l(t-1)}$$

Where {I} is the set of all irrigated land and {U} is the set of all unirrigated land, and β_λ is the flexibility constraint for the increase in irrigation. These flexibility constraints were estimated by using annual average changes over quintennial periods recorded in the Census of Agriculture.

Constraints on the land market are modelled by equation 13.

$$(13) \quad SELLAND_{lt} \leq (1 - \bar{\beta}_l) \sum_{i=1}^{17} x_{il(t-1)}$$

$$\forall l \varepsilon \{L\}.$$

The flexibility constraints for the sale of land were derived the same way as the flexibility constraints for crops. Data for land in farms over the past 40 years was used to estimate the maximum and minimum changes.

Pest Population Dynamics and Control

To model the response of farmers to policies which change their decisions to apply pesticides, one must take into account the way that these changes affect pest population dynamics. In modeling pest population dynamics, three things are relevant to economic decision making: quantity of sprays, timing of sprays and pest population effects on yield. With programmed spraying, quantity and timing of sprays are set a priori. Yields vary randomly with population density. As pest population density increases, pest damage to crops increases and this damage decreases the final yield of the crops. This relationship can be statistically estimated. Most production studies use expected yield to make the model deterministic.

Different pest management practices are presented to farmers as behavioral alternatives. Farmers will adopt those strategies which are successful. Those which are unsuccessful will cause farmers to continue to search for new techniques. The use of certain pest control techniques will lead to changes in the biological system. These changes will feed back into the economic system and will cause the state variables to change. The model captures the changing resistance of pest populations through feedback.

When modelling IPM, the timing, and sometimes even the application rates are no longer deterministic. They will vary according to pest population. Spraying will occur when the pest population meets or exceeds a certain threshold. To monitor the pest population, fields are scouted at regular intervals. If the pest population exceeds a given threshold, then some action is taken to control the population. Let DD represent degree days, CPB represent Colorado potato beetle population. Potato beetle population can be mathematically represented as (Logan):

$$(14) \qquad CPB = e^{b_0+b_1*DD+b_2*DD^2+b_3*DD^3}$$

where e is the base of natural logarithms. The double log form of equation 14 was used to estimate this relationship by a Maximum Likelihood Estimator (Logan). The density of CPBs over the growing season (A) is an important factor in determining the damage to potato crops. This is found by taking the integral (Logan):

$$(15) \qquad A = \int_0^{\overline{DD}} CPB(DD)\ d(DD)$$

The value of A was then used to predict the yield loss caused by CPBs (Logan):

$$(16) \qquad Y = Y_m(1 - 0.000168A).$$

Where Y = the predicted yield and Y_m = the maximum yield. The coefficients b_0, b_1, b_2, and b_3 must be estimated for each different set of field history, infestation, and management practices. The coefficients which were estimated by Logan were adjusted for Long Island conditions. Population growth is then modelled for each scouting period, two weeks, beginning in May and ending in September. The decision to spray can be represented as

$$(17) \qquad \begin{cases} \alpha_{\Phi} & \text{if CPB} \geq \text{threshold} \\ 0 & \text{if CPB} < \text{threshold} \end{cases}$$

When pesticides are applied, a certain percentage of the beetles will be killed. This percentage, known as the mortality rate, is a function of the size of the dosage, the toxicity of, and the resistance in the insects to the pesticide being used. The rate of survival, S, can be thought of as

$$(18) \qquad S_{\psi t} = CPB(1 - MR_{\psi t}) \qquad \{0 \leq MR \leq 1\}$$

where S is the survival rate, and MR is the mortality rate. The insects then recover from this level, and continue their growth. This model assumes that growth rates are unchanged by insecticide application and remain affected only by time and temperature.

The mortality rate declines over time as the insects become resistant to a given pesticide. This introduces a recursive aspect to the model, requiring a feedback loop which accounts for the declining efficacy of a pesticide. This states that for a given year, t, the mortality rate associated with a given pesticide will be a function of whether or not that pesticide was used the previous year. This relationship is shown is equation 19.

$$(19) \qquad M_{\psi l t} = \frac{M_{\psi l(t-1)}}{R_{\psi}}$$

Where R_{ψ} is the resistance factor of pesticide ψ.

Equation 20 makes sure that the total amount of pesticides used for all crops adds up to the amount used for each crop. Pesticide application rates for potatoes and other crops are explained in Baker.

$$(20) \qquad \sum_{i=1}^{17} \sum_{l=1}^{8} a_{il\psi t} \, x_{ilt} = \Psi_{\psi t} \; .$$
$$\psi = \{1, \ . \ . \ . \ ,21\}$$

The base year chosen for this study was 1983. A model solution consisted of simulating five growing seasons. Each growing season was broken up into two week scouting periods.

Policy Analysis

Different policies are summarized in table 1. In addition to a laissez faire scenario, variations on prohibitions, taxes and subsidies, and control of cultural practices are considered.

Table 1

Policies Considered for Analysis

1. Base Run (laissez faire).
2. Ban aldicarb.
3. Ban aldicarb, carbofuran and oxamyl.
4. Tax on aldicarb, carbofuran and oxamyl.
5. Tax on growing potatoes.
6. Purchase of chemical/crop rights.
7. Forced rotation out of potatoes.
8. Pest control districts.
9. Moratorium on potatoes.

All of the policies analyzed, with the exception of the base run and the policy taxing pesticides, assume that the pesticides which have been banned or removed from the market are not available for use on Long Island. This assumption reflects that re-registration of the banned pesticides is politically unacceptable.

Ban on Selected Pesticides

The first modification made of the laissez-faire model is a ban on aldicarb. This was done by simply adding a constraint to the LP model which required aldicarb loadings be less than or equal to zero.

$$(21) \qquad \sum_{\substack{i=1 \\ \Psi_{il}}}^{17} \sum_{\substack{l=1 \\ \varepsilon \Psi_b}}^{8} \Psi_{il} \leq 0$$

Where Ψ_b is the set of banned pesticides. Runs were made with bans on aldicarb only; aldicarb and carbofuran; and aldicarb, carbofuran and oxamyl.

The dual, or shadow price for the constraint banning aldicarb ranges between $24 and $47 per pound of active ingredient over the five years. This would be the amount a farmer should be willing to pay per pound of active ingredient of aldicarb if there were no constraints on the purchase of aldicarb. The banning of aldicarb results in its replacement by carbofuran, which dominates other pest control alternatives, but not to the degree that aldicarb did. Carbofuran, like aldicarb, was followed by replacement by substitute methods of pest control when resistance developed. However, the substitution is very small, as carbofuran is used on 100% of all potato land the first four years and 99% the fifth and final year.

The current policy, where aldicarb, carbofuran and oxamyl are not available to farmers for use, is the next considered. A constraint forcing carbofuran applications to be less than or equal to zero was added to the model. The oxamyl program was removed from the model, and a pest control decisions were based upon a choice between the pesticides kryocide, pydrin and rotenone.

Taxes and Subsidies

Economists have long favored taxes and subsidies as an efficient means for dealing with externalities. A tax on externalities would make the private cost of those inputs more closely reflect the social cost which they inflict (Baumol and Oates). The implementation of a tax on agricultural inputs has several advantages over other measures to remedy their pollution. Because many producers are involved, the cost of enforcing practices would be high compared with the cost of setting and collecting a tax. A tax provides an incentive for the farmer to reduce the amount of the input. If the farmer reduces chemical inputs, the amount of pesticide or fertilizer which reaches the saturated zone of the soil is reduced.

With the tax, the farmer's objective function becomes

$$(22) \quad \text{MAX} \sum_{i=1}^{17} p_{it} y_{it} - \sum_{i=1}^{17} \sum_{l=1}^{8} c_{it} x_{ilt}$$

$$- \sum_{\psi \varepsilon b} (c_{\psi t} + TAX_{\psi t}) \Psi_{\psi t} - \sum_{\tau=1}^{3} w_t \, HLAB_{\tau t} - \sum_{l=1}^{8} A_{lt} SELLAND_{lt}$$

In spite of their market efficiency, taxes on externalities have never received much attention in the United States. The efficient taxation of externalities present analysts with an infinite number of choices of how to model taxation. Optimal taxation requires information not only of the marginal product of the externality, but also of the social welfare trade-off between pollution and production.

The value of the marginal product of pesticides can be estimated with some precision, but the preferences of society can only be reflected in the political process, as there is no market for pristine environment. The optimal tax on pesticide will vary from pesticide to pesticide, depending on its price, marginal product, toxicity, and environmental characteristics. A tax on all pesticides at the same rate would be an inefficient way of reducing potato acreage and may also fail to reduce the use of those which have the greater threat to the environment.

Parametric programming was used to discover the tax rates which would cause farmers to shift to pesticides other than those which were banned (Baker). The taxes selected by parametric analysis were $125 per pound of active ingredient of aldicarb, $65 per pound of active ingredient of carbofuran and $70 per pound of active ingredient of oxamyl.

An alternative way to tax the externalities caused by pesticides is to tax the crop that requires their use. This is specified in the model by a transfer row which reduces income a given amount for every acre of potatoes grown. The objective function then becomes:

$$(23)\quad \text{MAX} \sum_{i=1}^{17} p_{it} y_{it} - \sum_{i=1}^{17} \sum_{l=1}^{8} c_{it} x_{ilt} - \sum_{i \varepsilon p} TAX_p x_{it}$$

$$- \sum_{\psi=1}^{21} c_{\psi t} \Psi_{\psi t} - \sum_{\tau=1}^{3} w_t HLAB_{\tau t} - \sum_{l=1}^{8} A_{lt} SELLAND_{lt}$$

Where TAX_p is the tax per acre of potatoes grown. Sensitivity analysis was performed to determine the amount tax that would reduce potato acreage (Baker). The model was run with a tax of $750 per acre. This is between 40% and 50% of gross and between 50% and 60% of net margin per acre. The lower yielding North Fork unirrigated continuous potato land leaves production first. The last land to leave production of potatoes is South Fork land which is irrigated and grown in rotation with field crops.

These tax levels seem high. It should be remembered that the tax reduces the margin on potatoes and does nothing to otherwise enhance the value of other crops. With labor as a constraint preventing the wholesale shift into high-value labor intensive crops, it is not surprising to see farmers choose lower profits before producing other crops.

Below $750, it seemed unlikely that the tax would be an effective incentive for farmers to shift production. Above $1000, the tax has roughly the same result as a ban on potatoes. No potatoes are grown, no tax is collected, income is roughly the same.

A conservation subsidy program would pay farmers to grow low-input crops. The crops which are included in the program are rye, oats, wheat, soybeans, sunflowers and dry beans. Other crops were not included because there is a lack of information on how to grow these crops without the chemical control of pests. An analyst who attempted to include other crops would face the arduous task of collecting a second set of budgets for each crop, grown without the use of many or any pesticides.

This program is more restrictive to farm income than would be a program which purchases chemical rights and permits farmers to grow any crop. The conservation subsidy was considered on an individual acre by acre basis, so that land on a farm in the program could be used to grow potatoes. Because this approach uses economic incentives, rather than legal sanctions or financial disincentives, it is the most lucrative policy for farmers of the ones examined.

A transfer row was introduced to the LP model which caused gross margin to increase by \$750 for each acre of the low-input, conservation crops grown.

The objective function becomes:

$$(24)\quad \text{MAX} \sum_{i=1}^{17} p_{it} y_{it} - \sum_{i=1}^{17} \sum_{l=1}^{8} c_{it} x_{ilt} + \sum_{i\varepsilon\lambda} \sum_{l=1}^{8} \text{SUBS}_{it}\, x_{ilt} - \sum_{\tau=1}^{3} w_t\, \text{HLAB}_{\tau t} - \sum_{l=1}^{8} A_{lt}\, \text{SELLAND}_{lt}$$

Where SUBS_{it} is the subsidy for crop i in year t, and λ represents the set of low-input crops which are subsidized. As with the taxation programs, sensitivity analysis was performed to discover the rate of taxation which would cause a significant change in the optimal solution. The analysis of the base year suggested that below \$700 per acre there would be minimal response to a conservation subsidy program. There would be a certain number of acres in non-host crops even if there was no program subsidizing their cultivation. Above \$1000, there would be few acres which would not be enrolled in the program. However, the cost of the program at \$26 million per year could be prohibitively expensive for local government.

The conservation subsidy program frees up potato labor so that more acres of labor intensive crops can be grown. The low-input crops selected are also the least labor intensive. Therefore, not only is the acreage in small grains increased, but so is the acreage in vegetable crops.

Control of Cultural Practices

A constraint was introduced which required that half of the land used to grow potatoes the previous year had to be used to grow another crop. The use of crop rotation as a pest control strategy introduces another dynamic element to the model, as seen by equation 25.

$$(25) \qquad \sum_{i=1}^{17} \sum_{l=1}^{8} x_{ilt} \geq 0.50\, x_{j(t-1)}$$

The constraints on irrigation (equations 26 and 27) reflects the reluctance of farmers who have invested in irrigation to dismantle their equipment, and the reluctance of farmers who have not invested in irrigation to purchase equipment which will not be used to its full potential. These constraints are given by equations 26 and 27.

$$(26) \qquad \sum_{\substack{i=1 \\ l \varepsilon \{I\}}}^{17} x_{ilt} \leq (1 - \bar{\beta}_1)\ \mathrm{LAND}_{1(t-1)}$$

$$(27) \qquad \sum_{\substack{i=1 \\ l \varepsilon \{I\}}} x_{ilt} \geq (1 + \underline{\beta}_1)\ \mathrm{LAND}_{1(t-1)}$$

The pest control district performs four functions specified in the model. First, it regulates the rotation of crops involving potatoes; second, it controls the decision over which pesticide to use, rather than the farmers; third, it provides labor for scouting and the materials for pest control free of charge to farmers; fourth, participation is mandatory and there is no way for a farmer to opt out.

The pest control district model also required rotation. The crop rotation requirements for this model are the same as those given in equation 25. The irrigation constraints in equations 26 and 27 are also part of the pest control district model. Equations 4 and 5 are replaced by equation 28 and 29 to reflect the fact that neither family nor hired labor is used for scouting and pesticide applications.

$$(28)\quad \sum_{i=1}^{17} \sum_{l=1}^{8} a_{is\tau} x_{ilt} + \sum_{i \neq p} \sum_{\psi=1}^{21} \sum_{l=1}^{8} a_{i\psi s\tau} \Psi_{\psi lt} \leq FLAB_{\tau}$$

$$\tau = 1, \ldots 3$$

$$(29)\quad \sum_{i=1}^{17} \sum_{l=1}^{8} a_{iu\tau} x_{ilt} + \sum_{i \neq p} \sum_{\psi=1}^{21} \sum_{l=1}^{8} a_{i\psi u\tau} \Psi_{\psi lt} \leq HLAB_{\tau}$$

$$\tau = 1, \ldots 3$$

The subscript p represents the set of potato growing activities. The price of pesticides to farmers was set to zero. The farmer no longer has to provide labor for pest control. All labor, including spraying, is assumed to be provided by the district. No other labor requirements are changed.

The values for α_{Φ} were raised. Pesticide applications were limited to a synthetic pyrethroid with low mammalian toxicity and short half-life, Pydrin, used with a synergist, PBO. A requirement was made that at least one fifth of the applications use rotenone to forestall the build-up of resistance.

To reflect a moratorium on potatoes, a constraint is introduced in the first year that limits the acreage of potatoes to zero. This is given by equation 30.

$$(30) \qquad \sum_{i \varepsilon p} \sum_{l=1}^{8} x_{ilt} \leq 0 \qquad t=1$$

The first year of the run sets the maximum level at which potatoes can be grown at zero. The first year following the ban on potatoes sets the constraint on the maximum number of acres in potatoes at the number of acres grown in field crops the previous year. The model probably underestimates the acreage in potatoes after the moratorium is lifted. Because so many acres are in field crops in the previous year, minimum acreage requirements set by the flexibility constraints for the field crops prevent all the land in field crops in 1984 from going into potatoes.

Effect on Income

The different policies have different effects on farm income. Incomes associated with the different policies examined are discounted and presented in table 2. The policy which results in the highest farm income is the conservation subsidy. This is followed by the laissez faire policy and the policy which taxes the pesticides which have been banned. The policies which ban the use of the carbamates aldicarb, carbofuran and oxamyl do not yield as high an income as the previously mentioned policies. Policies with lower incomes are, in descending order, pest control districts, a moratorium on potatoes, crop rotation, and a tax on potatoes.

While the crop rotation has a higher margin than banning potatoes in the first year, the control of potato pests is less complete, and resistance of the Colorado potato beetle to available pesticides is higher. These factors lead the crop rotation to perform less well economically over the long run than a moratorium. The two incomes are close, and are probably underestimated because of the conservative handling of changes in population dynamics brought on by rotations.

Table 2
Average Annual Net Present Value Gross Margin Under Different Policies

-million dollars-
Discount Rate

Policy	0%	3%	5%
Laissez Faire	35.145	33.223	32.059
Ban Aldicarb	33.794	31.942	30.821
Ban Aldicarb, Carbofuran, Oxamyl	32.760	30.962	29.873
Tax Banned Pesticides	32.959	31.148	30.051
Tax Potatoes	24.732	23.358	22.527
Purchase Chemical Rights	37.214	35.192	33.968
Crop Rotation	28.049	26.434	25.457
Ban Potatoes	28.536	26.851	25.830
Pest Control District	31.474	29.717	28.654

Discounting the income streams did not reverse the advantage that a moratorium has over crop rotations, although the difference was narrowed. A moratorium would cause a sharp loss in income over the first two harvests, and, as such, it would be probably be unattractive in spite of its long run benefits.

With all policies that cause potatoes to be shifted to more labor intensive crops, it should be remembered that the availability of labor over the growing season will remain an important constraint in the transition of Long Island agriculture. The labor constraint seemed to work against cauliflower and sweet corn to a greater extent than cabbage.

It is interesting to compare the solution under a conservation subsidy program with the solution of taxing potato acreage. The asymmetry between taxes and subsidies is thus shown. The tax is more effective than the subsidy at reducing potato acreage and pesticide loading rates. On the other hand, the subsidy enhances gross margin, while the tax is detrimental to farm income.

The taxation of chemicals is interesting because it results in a higher margin than the current policy. A tax on chemicals is economically more efficient than a ban. The market is given more consideration in allocating inputs. However, a tax which is set too low, as the tax on carbofuran seems to have been, can mean that the tax does not adequately reflect the social cost of the pesticide.

Crop Response

Crop response to different policies are given in three categories: Potato acreage, grain acreage, and vegetable acreage. Potato acreage is given in table 3.

The change in crop acreage calculates the difference between 1988 predicted levels (1988_P) and 1984 actual levels (1984_A) in thousands of acres.

Table 3

Potato Acreage for the Different Scenarios
1984 and 1988
(thousand acres)

Policy	1984	1988	Change (1988_P-1984_A)
Laissez Faire	15.4	12.6	-1.4
Ban Aldicarb	14.2	11.6	-2.4
Ban Aldicarb, Carbofuran, Oxamyl	14.1	10.9	-3.1
Crop Rotation	3.3	7.5	-6.5
Tax Banned Pesticides	13.8	11.1	-2.9
Tax Potatoes	8.7	5.0	-9.0
Purchase Chemical Rights	10.8	8.7	-5.3
Pest Control District	7.8	8.7	-5.3
Ban Potatoes	0.0	7.7	-6.3

Potato acreage would continue to decline even if pesticides were not banned. Banning pesticides, however, accelerates the decline. Ironically, policies expressly designed to reduce potato acreage are less successful in acheiving that end than taxing potatoes.

Table 4 shows the change in acreage of rye, wheat, field corn, soybeans, oats, and other grains.

Table 4

Grain Acreage for the Different Scenarios 1984 and 1988 (thousand acres)

Policy	1984	1988	Change (1988_P-1984_A)
Laissez Faire	6.0	3.7	-2.3
Ban Aldicarb	6.1	3.7	-1.4
Ban Aldicarb, Carbofuran, Oxamyl	6.5	4.5	-1.5
Crop Rotation	17.1	7.9	1.9
Tax Banned Pesticides	6.9	4.3	-1.7
Tax Potatoes	11.7	9.4	3.4
Purchase Chemical Rights	10.2	6.5	0.5
Pest Control District	12.4	6.0	0.0
Ban Potatoes	18.2	6.2	0.2

Grain acreage declines most rapidly under the laissez-faire scenario; a tax on potatoes causes grain acreage to increase the most. Bans on the pesticides slows the transition out of grain. Grain acreage increases with crop rotation, and stays about the same with the pest control district, purchase of crop rights and the ban on potatoes.

The aggregate acreage of cauliflower, cabbage, sweet corn and other vegetables are given in table 5.

Table 5

Vegetable Acreage for the Different Scenarios 1984 and 1988 (thousand acres)

Policy	1984	1988	Change $(1988_P - 1984_A)$
Laissez Faire	10.9	10.9	-0.2
Ban Aldicarb	11.0	11.9	0.7
Ban Aldicarb, Carbofuran, Oxamyl	11.3	12.0	0.8
Crop Rotation	12.6	12.4	1.2
Tax Banned Pesticides	12.5	12.1	0.9
Tax Potatoes	12.9	13.6	2.4
Purchase Chemical Rights	12.2	12.1	0.9
Pest Control District	13.1	12.7	1.5
Ban Potatoes	16.8	13.8	2.6

For all scenarios but the laissez-faire, vegetable crop acreage increases. This is consistent with the move to specialty crops. The increase is most marked with the ban on potatoes and the tax on potatoes.

Environmental Impact

Unlike farm income, pesticide use does not lend itself to be analyzed by a single parameter, or even with a common unit of measurement. Pesticides have different characteristics and properties which make them have dissimilar environmental impacts. Some are more toxic than others, some more persistent. Because of the multi-attribute nature of environmental risk, a single number cannot give an absolute measure of risk. However, by a combination of these quantitative attributes, one can derive a relative measure of risk. The result is a qualitative measure which can be used to rank alternative policies for their potential hazard to public health and the environment.

Concentration of a given contaminant is a function of soil characteristics, such as bulk density, porosity, organic matter content, pH, and moisture content; plant cover and uptake; rainfall and temperature; the characteristics of the pesticides, such as adsorption to soil, solubility, volatilization, longevity and plant uptake; and management practices, such as number of applications, application rates, and incorporation into soil. The indices used are based on chemodynamic properties of different pesticides. The fate of pesticides depends on aqueous solubility (SOL_{ψ}), measured in mg/L; vapor pressure (V_{ψ}), measured in Pascals; and adsorption, (Koc_{ψ}), measured in L/Kg; and half-life ($t½_{\psi}$), measured in days. The soil and climate characteristics mentioned above in connection with groundwater models are also important in determining fate of pesticides. However, for the purpose of this study, these are assumed homogeneous for the region of study.

As half-life and solubility increase, leaching potential increases. As vapor pressure increases, more of the pesticide is volatilized and less is apt to reach the groundwater. Similarly, if a pesticide is likely to be adsorbed to soil particles, it is less likely to reach the groundwater. A cumulative leaching index for each of these policies based on these principles (LEACH) is presented in equation 21 (Laskowski, Goring, and Swann).

$$(21) \quad LEACH = \sum_{\psi \varepsilon \Psi} \frac{SOL_{\psi} * t½_{\psi}}{V_{\psi} * Koc_{\psi}} * \Psi_{\psi}$$

This number for each policy is then divided through by the result for the current policy (the ban on aldicarb, carbofuran and oxamyl) for easier comparison.

To take into account the acute toxicity of pesticide use under each policy, leaching potential is divided by the LD_{50} for each pesticide. As LD_{50} decreases, toxicity and hazard increase. This is represented by HAZARD in equation 22.

$$(22) \quad HAZARD = \sum_{\psi \varepsilon \Psi} \frac{LEACH_{\psi}}{LD_{\psi}} * \Psi_{\psi}$$

The policy with the highest leaching potential is the laissez faire policy. This is not surprising, given the large amount of aldicarb used under this policy. The next highest leaching potential is associated with the policy which bans aldicarb, but not carbofuran or oxamyl. The policy with the lowest leaching potential is the moratorium on potatoes. This is consistent with the lower pesticide use on alternative crops. The remaining policies all have roughly the same leaching potential, with the taxation of chemicals showing the highest and rotation showing the lowest. The pest control district ranks relatively high with the leaching index.

The ranking of the policies under the hazard index has several important differences. Rather than being the third most environmentally damaging policy, pest control districts are the fourth least damaging, behind the moratorium on potatoes, forced crop rotations, and the tax on potatoes. The relative rankings of the two policies are summarized below in table 6.

The laissez faire policy is unquestionably the most harmful to the environment. The evidence of this is plain from the contamination levels of aldicarb and carbofuran in the drinking water near potato fields. Aldicarb levels would exceed the MCL in the plume near fields in continuous potatoes. The banning of these pesticides is a sound remedy, and a good basis for other policies.

Table 6
Comparison of Environmental Indexes

	Leach Index Totals	Leach Index Rank	Hazard Index Totals	Hazard Index Rank
Laissez Faire	59.53	1	11,539	1
Ban Temik	1.99	2	0.97	3
Ban Furdan & Oxamyl	1.00	6	1.00	2
Pest Control District	1.44	3	0.60	6
Ban on Potatoes	1.04	4	0.41	9
Pesticide Tax	1.03	5	0.94	4
Tax on Potatoes	0.23	9	0.44	7
Purchase Chemical Rights	0.38	7	0.76	5
Crop Rotation	0.25	8	0.43	8

Conclusion

The current policy does not make anybody better off without making somebody else worse off. Neither does any other policy. Nonetheless, analysis suggests that there is room for improvement. Simply requiring farmers to reduce potatoes reduces the amount they use of most pesticides. This is done at the expense of farm income. By itself, crop rotation is not the answer to the problem over the long run. It is a palliative solution which fails to provide additional incentives to grow crops other than potatoes. The policy would be relatively easy to administer and would best be left up to local government. The need to balance voluntary compliance and police power over management decisions makes it unlikely that it will gain the public support needed to fully implement it. It is also unlikely that farmers would volunteer to comply with an institution which would reduce their incomes for a few years to possibly stabilize income and yield in the future.

To put the losses by farmers into perspective, the value of groundwater needs to be considered. For Long Island, the aquifer is worth the price of the next alternative source of drinking water, estimated to be between $5 and $10 billion. Nobody can say for certain how much it would cost to replace the Long Island aquifer as a source for drinking water. In the extreme, the alternatives would require the transportation of water from upstate New York and Connecticut. As long as enough clean water remains on Long Island, measures can be less costly, but still can create great financial burdens for water suppliers and local government. For the North Fork alone, treatment for water contaminated by agricultural chemicals were estimated to cost between $7 and $21 million. While no single figure can capture the risk and the willingness to pay for clean water, it is apparent that Long Island groundwater is a precious resource in need of special protection. The sacrifices thus far on the part of farmers have not been excessive in light of these estimates, and, in light of future contamination, efforts to reduce the possibility of pesticide leachate should be undertaken.

The purchase of crop rights appears to be an attractive policy, because it has the highest farm income and one of the lowest environmental impacts. However, at an estimated annual cost of $26 million per year, such a program is likely to be prohibitively expensive for a local government already saddled with a purchase of development rights program of comparable magnitude. Annual cost is estimated to be between $5 and $7 million at $750 per acre. The level of government most likely to be responsible for a rights purchase program is the county. Suffolk county government is already having severe difficulty with the cost of its Purchase of Development Rights program. Farmers already receive tax breaks where they own land in agricultural districts. The county is unlikely to have the will to spend a great deal more on transferring income from non-farmers to farmers. The policy which bans potatoes for two years, for all of its promise in reducing pest populations to manageable levels, is so costly in its first year that it is unlikely to generate much support. The administration could be the same as either crop rotation or the pest control district. The income loss the first year would be approximately $4 million compared with the current policy.

The model almost certainly underestimates yields and income brought about by those programs which include rotation into non-host crops. This is partially captured, but because of the lack of data it was impossible to estimate how changes in cropping patterns change pest dynamics. Whether this bias makes a significant difference with respect to these policies' performance, it is impossible to say without the data. More field data ought to be collected for any pest control program which is implemented.

The taxation of chemicals would have to take place at the state or federal level. Taxation would be almost as socially unacceptable as the laissez faire policy in this instance.

The taxation of land planted in potatoes would be the most difficult for farmers, even more than crop rotations. An estimated 14% to 20% of farm income would be taxed away. The amount of tax that would be required to make the tax an effective device may not be acceptable. Farmers have already had difficulty adjusting to the banning of pesticides. If potato land were taxed, potato farmers would be free to choose the way they want their income reduced. Of all the policies, the taxation of land planted in potatoes probably underestimated the conversion to non-agricultural uses the most.

The hybrids of some of the policies which were examined in this study have interesting possibilities. One hybrid of particular interest is the combination of taxation of potatoes with the subsidization of low input non-host crops. The high cost to farmers of the tax on potato land, as well as the cultivation of some crops which are heavy users of pesticides makes it a worst case option in many ways. Of all the options, taxing potatoes would probably result in the greatest loss of agricultural land to non-agricultural uses. One advantage it has is that it costs the public very little. While it does reduce potato acreage, it does not eliminate it. On the other hand, the subsidization of low input crops gives farmers a high return and does a better job than most policies at the reduction of pesticide applications.

By combining a taxation with a subsidization program, the subsidies would offset the loss of farm income, while the taxes would give additional revenue to the county government. Farmers would face both positive and negative incentives to switch out of potatoes and would be willing to sell their rights at a lower price. Taxes and subsidies are likely to be asymmetric, and the program would either need to be augmented by general revenues, if the subsidy rate was high relative to the tax rate, or would reduce total farm income if the tax rate was high relative to the subsidy rate.

Administration of a combined tax/purchase program would likely require careful attention to crop prices, input prices and the loss of land to non-agricultural uses. A combination of the purchase of crop rights with a pest control district would also be likely to increase farm income, while reducing the need for pesticide use. This would also increase the fiscal and administrative burden on local government over and above either program. However, many aspects of administration could be combined, such as the monitoring of crop rotations and coordination of pesticide application programs.

The author's opinion is that the most favorable policy for balancing economic, environmental and agricultural would be a program that coordinated pest control practices and provided farmers a service for ecologically safe, economically sound means of controlling potato beetle populations. The adoption of such a program faces many obstacles. The first obstacle is one of distrust and apathy on the part of farmers. Farmers need to be convinced of the long run benefits of coordinating pest control, and that such a program is not just another way for big government to try and run their lives. The start up costs and initial administrative burdens of such a program would lend credence to their skepticism. The development of such a district would require the initiative of farmers who were concerned enough to mobilize. If pesticide failures become severe, more severe than predicted in the model, this could be a force that mobilizes the farmers to adopt a pest control district. Lacking that incentive, it is unlikely that farmers will adopt a pest control district on their own, without outside intervention. The existence of outside intervention would fuel their suspicion of government action and any attempt to impose a district in Suffolk County from above would face strong resistance. There would be in some cases, the incentive to cheat by augmenting publicly provided pesticide applications with one's own sprays. The perceived gains from cheating are likely to increase the less a district appears to have the interest of farmers in mind. To succeed, the district must have the tacit, voluntary support of the majority of potato growers on Long Island.

A pest control district would also need to overcome the suspicion of environmental groups which might perceive a district as a pawn in the hands of farmers, able to run roughshod over the environment with chemical applications. As we have seen, a pest control district does not necessarily have the lowest environmental impact or hazard to groundwater associated with it. However, pesticide programs can be fine-tuned to reduce groundwater impacts, particularly with increased information on the transport of pesticides to groundwater. A pest control district can also serve as a conduit for the latest methods of biological control developed by the Land Grant college, facilitate adoption of new technology, and move up the learning curve faster than individual farmers would.

Pest control districts would require the initiative of potato farmers and would have to confront the dilemma that is at the heart of this study. The way that pest control districts balance their regulatory and service functions must be carefully considered. The institutional mechanisms of a pest control district would have to be flexible enough to confront changing economic and environmental conditions. Therefore, the federal and even state levels would be inappropriate for administering its day to day functions. Because it would cover a geographically small, but densely populated and intensively farmed area, local government should be able to handle the required duties. However, cooperation with and technical assistance from state and federal government would be important for the success of the program.

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